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Experimental study about the influence of adhesive stiffness to the bonding strengths of adhesives for ceramic/metal targets

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Abstract

The aim of the investigations presented here was to understand how the stiffness of the adhesive affects the failure of ceramic tiles adhered to metallic backings. The working hypothesis was that varying the adhesive stiffness could have the same effect on the ballistic performance as a variation of the adhesive thickness.

Two different projectile/target combinations were utilized for ballistic tests in order to generate extremely different loading conditions. With targets consisting of 6 mm aluminum oxide ceramic and 6 mm aluminum backing, complete penetration occurred in each test with 7.62 mm tungsten carbide core AP ammunition at an impact velocity of 940 m/s. In contrast, with ceramic tiles of 20 mm thickness on 13 mm steel backing, no penetration of the ceramic occurred at the impact of a 7.62 mm ball round at 840 m/s.

Four different types of adhesive (high-strength till high-flexible) were tested in both configurations. The elongation of the adhesive layer, the deformation of the metallic backing and the failure of the ceramics were observed by means of a high-speed camera during the projectile/target interaction.

The results of the ballistic tests showed that a higher fracture strain caused a larger deformation of the backing compared to adhesives, which exhibit a high tensile strength and low fracture strains.

The experimental results indicate that the damage behavior of the ceramic/metal composites depends on the absolute elongation of the adhesive layer. This can be controlled either by the thickness or the stiffness of the bonding layer.
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1. Introduction

Beside excellent protection properties, weight is one of the important parameters of modern armor systems. To fulfill such boundary conditions the use of composite armor is an opportunity. Therefore modern lightweight armor consists of different classes of materials. A technique to combine the different materials is the use of adhesives. Thereby polyurethane and epoxy based adhesives are commonly used to bond ceramic armor systems [1]. Knowledge of the influence of the adhesive properties on target damage, deformation and the ballistic resistance is of importance for composite armor design. A parameter that is often discussed is the thickness of the adhesive layer. Zaera et al. [2] studied the influence of adhesive stiffness and thickness on ceramic damage and the deformation of the aluminum backing plate for targets. An optimum adhesive layer thickness with respect to the ballistic limit velocity for Al_2O_3-Al targets was observed by Lopez-Puente [3]. Prakash et al. [4] reported a non-monotonic variation of projectile penetration into the backing with variation of the adhesive thickness.

However, polyurethane and epoxy based adhesive systems show different mechanical behavior. Epoxy adhesives are less ductile than polyurethane ones, which exhibit a higher fracture strain. Former studies, e.g. by Zaera [2], showed that a thicker adhesive layer affected the performance of bonded ceramic/metal targets. A thicker adhesive layer led to an increased plastic deformation of the metallic backing and as a result of the plastic deformation resulted to a reduced projectile velocity. The damage pattern of the ceramics tiles also changed with a varying layer thickness. Zaera explained this behavior primarily by the increasing layer thickness [2]. However, due to the different elastic moduli of the adhesive materials, different absolute strains of the adhesive layer can occur. Therefore, the hypothesis was postulated that the

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Fig. 1. Photographs of type A targets: (a) top view and (b) front view.

adhesive stiffness could have the same effect on the ballistic performance of ceramic/metal targets. In order to verify this hypothesis, two different projectile/target combinations were utilized. In previously published work [2–4] only the extreme of complete penetration of ceramic/metal targets by an armor-piercing projectile was considered. In order to derive a better understanding of the influence of the adhesive stiffness, another test configuration was designed, where almost no penetration of the projectile into the ceramic occurs.

2. Experimental methods

2.1. Target description

Two types of targets were manufactured. Target type A, which is illustrated in Fig. 1, was derived from the work of Zaera [2] and Lopez-Puente [3]. The target was assembled from nine alumina tiles (ALOTEC 99 SB, CeramTec-ETEC GmbH, Lohmar, Germany) of dimensions $50.5 \times 50.5 \times 6$ mm^3, which were bonded to an EN AW-2017A - T 451 alloy aluminum plate of dimensions $200 \times 200 \times 6$ mm^3. Glass beads with a diameter of 0.3 mm controlled the thickness of the adhesive layer. The surface of the aluminum plate was cleaned by means of isopropanol before the adhesive was applied. To achieve a uniform tile pattern, the tiles were fixed on a PE plastic film first, cleaned using isopropanol and then transferred to the prepared aluminum plate.

Target type B is shown in Fig. 2. To avoid a significant plastic deformation, the target consists of three $100 \times 100 \times 20$ mm^3 alumina tiles (ALOTEC 98 SB, CeramTec-ETEC GmbH, Lohmar, Germany), bonded to a high hardness steel backing (Secure M 450, Thyssen Krupp) of dimensions $13 \times 160 \times 500$ mm^3. Glass beads also controlled the layer thickness of the adhesives. To provide a clean surface, the surface of the metal stripes was sandblasted and afterwards cleaned by isopropanol. The adhesives were applied to the backing and then the isopropanol cleaned ceramic tiles were positioned.

2.2. Adhesives

Four adhesives were utilized: Sikaflex® 553 2K (Sika Deutschland GmbH, Stuttgart, Germany), Scotch Weld™ DP 490 (3M Deutschland GmbH Industrie-Klebebänder, Klebstoffe und Spezialprodukte, Neuss, Germany) and Loctite® 9489 (Henkel AG & Co. KGaA, München, Germany), hereafter named AD1, AD2 and AD3. For target type B instead of AD1 a related Polyurethane adhesive Sikaflex® 221 (Sika Deutschland GmbH, Stuttgart, Germany), AD4, had to be used. In contrast to AD1 and AD4, which are polyurethane hybrids or polyurethane based adhesive materials, AD2 and AD3 represent epoxy based materials. The used adhesives differ not only in their chemical base but also in their mechanical behavior. The epoxy based adhesives AD2 and AD3 exhibit a high tensile strain and, compared to AD1 and AD4, lower fracture strains. Properties and applications of the used adhesives are summarized in Table 1.

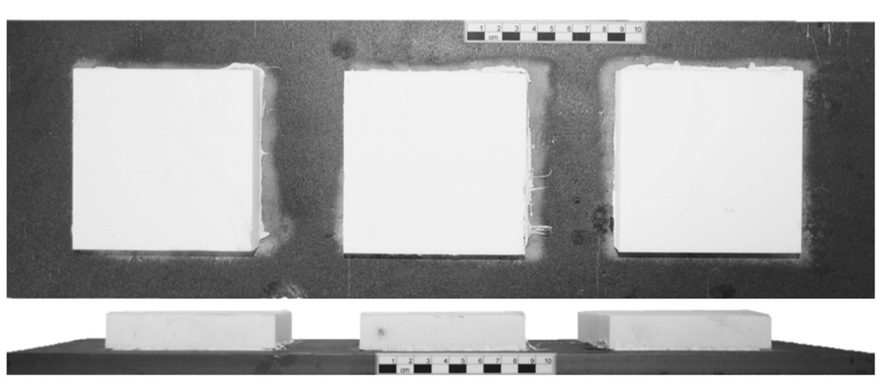

Fig. 2. Photographs of type B targets: (a) top view and (b) front view.

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